Research on the integration and scheduling method of intelligent cloud manufacturing resources for fully mechanized coal mining equipment

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Title page

Article Title: Research on the integration and scheduling method of intelligent cloud manufacturing resources for fully mechanized coal mining equipment

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Abstract: In view of the problems such as the overall low utilization rate of resources, the insufficient level of industry informatization, the prominent problem of repeated construction, and the insufficient level of innovation in the manufacturing process design of fully mechanized coal mining equipment, the integration and scheduling method of intelligent cloud manufacturing resources for fully mechanized coal mining equipment was studied. First, the necessity and importance of building intelligent cloud manufacturing resources integration and scheduling systems for fully mechanized mining equipment under the current situation were analyzed. Then, based on the underlying services of cloud computing and intelligent cloud manufacturing, the overall architecture of intelligent cloud manufacturing resources integration and scheduling systems for fully mechanized coal mining equipment was proposed, and the intelligent cloud manufacturing resources integration platform suitable for general and special technical services was designed. Then, a cloud scheduling method based on an adaptive genetic algorithm was proposed to realize the scheduling of cloud manufacturing resources. Finally, the practicability and operability of the system were verified by the cases. This study has realized the integration and sharing of resources, such as the design, calculation, data, simulation, and servicing of fully mechanized coal mining equipment under the intelligent cloud manufacturing environment.

Key words: fully mechanized coal mining equipment; resource integration; cloud manufacturing; cloud scheduling; genetic algorithm

1. Introduction

The manufacturing industry is the main body of real economy, the material basis of national security, and a reason for people's happiness and well-being. It also reflects a country's scientific and technological development level [1]. Therefore, governments of all countries always invest in the development of their manufacturing industries. For example, the high-tech strategic plan "industry 4.0" proposed by the German government aims to establish an intelligent and advanced manufacturing mode that is integrated with the Internet and which would improve the manufacturing efficiency, reduce its costs, and accelerate its response [2]. Also, the "made in China 2025" plan proposed by the Chinese government defines intelligent manufacturing as the main direction of China's manufacturing industry and aims at accelerating the construction of a strong manufacturing power, the development of an advanced manufacturing industry, and the deep integration of the Internet, big data, artificial intelligence, and real economy [3]. In addition, in its new strategic layout, the USA promotes the usage of the industrial Internet to subvert the value system of the manufacturing industry and use digital, new materials and new production methods to subvert the production mode of the manufacturing industry. With the rapid development of science and technology, the development of the manufacturing industry depends more on the promotion of high-tech applications. Li Bohu, an academician of the Chinese Academy of engineering, innovated a networked manufacturing mode by combining cloud computing, high-performance computing, IOT, and other technologies to propose the concept of cloud manufacturing [4, 5]. Then, he developed a new information and manufacturing technology and proposed the concept of "intelligent cloud manufacturing" [6], providing a good solution for the management, integration, sharing, and scheduling of

manufacturing enterprise resources. Under this guidance, the cloud manufacturing technology has made significant progress [7, 8].

Coal is one of the important energy pillar industries in the world, and its fully mechanized mining equipment (including roadheaders, crushers, shearers, scraper conveyors, transfer machines, water pumps, and mine hoists) play a significant role in coal mining. However, at present, the resources of design and manufacture of fully mechanized coal mining equipment are mainly scattered in colleges and universities, scientific research institutes, and enterprise technology research and development centers. The overall utilization rate of these resources is low, the industry information level is not enough, the problem of repeated construction is prominent, the design innovation is insufficient, and the effective resources sharing cannot be realized, and this has undermined the sustainable development of manufacturing coal mining equipment. At the same time, with the increasing market competition, the level of using information technology to transform traditional production mode and technological process of coal machine manufacturing enterprises needs to be improved urgently, so these enterprises have a strong demand for manufacturing resources [9]. This contradiction is the main problem to be solved in this study.

In recent years, intelligent cloud manufacturing has made a lot of breakthroughs in academic research and industrial applications. Many scholars have studied several key issues, such as service composition optimization strategies, platform security architecture, and scheduling in a cloud manufacturing environment [10-15], which provides useful references for the research in this study. In comparison with common engineering machinery, fully mechanized coal mining equipment are challenged with weak network transmission signals, difficult data and knowledge collection, complex manufacturing processes, and high manufacturing

costs due to their complex structure and difficult operating environments. Based on the technologies of mechanical design, advanced sensors, virtual simulation, monitoring and diagnosis, the Internet, genetic algorithms, this study studies the key technical issues facing the intelligent cloud manufacturing resources integration and scheduling of fully mechanized coal mining equipment while taking into consideration large-scale mining and transportation equipment, such as high mining electric traction shearers, super-heavy scraper conveyors, pump stations, crushers, roadheaders, and mine hoists. Also, the intelligent cloud manufacturing resources integration and scheduling system for mining and transporting various kinds of coal mining mechanical equipment was constructed, and the manufacturing resources, such as model selection designs, parametric modeling, virtual assembly and demonstration, equipment monitoring and diagnosis, computer aided engineering (CAE) analysis, knowledge management, key design technical services, general support systems, literature retrieval, technical training, practical technologies, and the regulations and standards required for mechanical design, were integrated. Moreover, the scheduling problem of cloud manufacturing resources was studied in-depth, and this study has realized the integration and sharing of resources,

including the design, calculations, data, simulations, services of coal mining, and transportation equipment under a cloud manufacturing environment.

2. An overall design of intelligent cloud manufacturing resources integration and scheduling system for fully mechanized mining equipment

2.1. Key infrastructure of cloud intelligent manufacturing

The industrial Internet is the infrastructure that supports key integrated information of intelligent manufacturing. Through a comprehensive and deep perception, real-time dynamic transmission, and advanced modeling analysis of industrial data, intelligent decision-making and control are necessary to drive the intelligent development of the whole manufacturing industry (Fig.1). In this study, the industrial Internet that connects relevant productive enterprises and technology research centers of fully mechanized coal mining equipment in Shanxi Province in China is established through a mobile special line. It aims to link the resources relative to the design, manufacturing, and information of relevant universities and enterprises, and it realizes the overall sharing of resources through the construction of the industrial Internet.

Fig.1 The supporting frame of industrial internet

2.2. Architecture of cloud manufacturing resources integration and scheduling system

Cloud manufacturing is proposed and developed on the basis of cloud computing. Based on the concept of “everything is service” in cloud computing, the concept of “manufacturing is service” is proposed. Generally, IaaS (Infrastructure-as-a-Service), PaaS (Platform-as-a-Service), and SaaS (Software-as-a-Service) are three service modes of cloud computing [16]. IaaS provides users with utilization services for all the computing infrastructure, including CPU,

memory, storage, network, and other basic computing resources, where users can deploy and run any software. PaaS provides services for user development languages and tools (such as Java, Python, and .Net), and SaaS provides application services for user operators to publish applications that run on cloud computing infrastructure.

Intelligent cloud manufacturing has been extended and expanded on the basis of the above services. Based on that, this study constructs the intelligent cloud manufacturing resources integration and scheduling system for fully

mechanized coal mining equipment, and the overall framework is presented in Fig. 2. The resource layer is used to collect, extract, and integrate all kinds of computing and manufacturing resources, and the virtual service layer is used to virtualize the resources and the virtual storage of data that can achieve remote extraction. The virtual layer also corresponds to the IaaS layer of cloud computing, and the global service layer includes all kinds of software frameworks, engines, data management and analysis, and middleware and cloud services that correspond to the PaaS layer of cloud computing. The application layer implements the relevant business applications of computing and manufacturing that correspond to the SaaS layer in cloud computing, and the user interface layer provides users with the necessary interface required to use the computing and manufacturing resources of each layer.

Fig.2 Overall framework of intelligent cloud manufacturing resources integration and scheduling system

3. Cloud manufacturing resources integration system

3.1 System function and implementation

In this study, based on the engineering background of large-scale mining and transportation equipment, such as shearers, scraper conveyors, pump stations, crushers, roadheaders, and mine hoists, the respective cloud

manufacturing resources integration platforms were established to provide the corresponding sharing and service functions. Each system function includes a general technical service support system and a special technical service support system.

The general technical service support system includes the system introduction, design system, rules and standards, practical technology, related academic papers, technical training, and user assistance functions of all the equipment platforms for the fully mechanized mining equipment. On the other hand, the special technical service support functions include the model selection design, parametric modeling, virtual assembly and motion display, CAE analysis system, knowledge management system, key technologies and fault records, and general support system. The specific function structure is presented in Fig.3.

Fig.3 Function of resources integration system

The system integrates the key parts of shearer, scraper conveyor, roadheader, mine hoist and the digital design, manufacture and test resources of the whole machine. It can shorten the design cycle, reduce the R & D cost, improve the product quality, optimize the equipment structure, improve the structure, stability and system dynamics performance of the whole machine and parts of fully mechanized coal mining equipment, improve the reliability of the equipment, and realize the digital collaborative design of fully mechanized coal mining equipment in the industrial Internet environment.

3.2 Function test

Taking the scraper conveyor as an example, this study introduces the basic functions of a scraper conveyor intelligent cloud manufacturing resources integration system. It can be divided into the scraper conveyor type selection design, parametric modeling, virtual assembly and motion display, CAE analysis, knowledge management, key technology and fault record, general support system, and other relative functions. The type selection design is mainly based on the parameters related to the design productivity input by the user (coal seam thickness, shearer cutting depth, solid density of coal), working face length, shearer traction speed, inclination, scraper type (bendable, non-bendable), transportation direction (up, down), etc. Then, the system automatically outputs the scraper conveyor model matching parameters and relevant parameters in addition to the corresponding selection report. Parametric modeling is mainly based on CAD technology and the secondary development of the UG model. First, the key dimension parameters of the components need to be determined, the system develops the COM components of the parametric model, compiles them into a dynamic-link library, and then uses the model display page to realize the call of the dynamic-link library so as to complete the modeling and model display process. The virtual assembly and motion display mainly use unity 3D to build a virtual model of the equipment, and the CAE analysis function completes the static analysis, the non-prestressed model analysis, and the transient analysis of the CAE component. The knowledge of the management system mainly completes the sorting, integration, query, update, and management of the scraper conveyor design resources, and the key technology and fault recording function completes the query of the fault history, including the fault phenomenon, fault reason, and fault handling methods. Furthermore, the general support system can realize the query and calculation of the general data. Fig.4 presents the page of the CAE static analysis for the dumbbell pin parts of the scraper conveyor.

First, the dumbbell pin size parameters and the part analysis parameters are input into the system, as presented in Fig.4(a). Then, the background will conduct the CAE static analysis according to the input parameters and then provide the results after the analysis, as presented in Fig.4(b).

Parameter list:

LA: 362	HB: 42	LB: 225	HC: 27
LC: 90	HD: 20	LD: 27	HE: 40
LE: 16	DI: 100	LF: 40	DE: 60
LG: 67	DI: 30	HA: 78	

CAE Analysis Input parameters:

Static Analysis	Non-prestressed modal analysis	Prestressed modal analysis	Harmonic response analysis	Transient analysis
Input parameters	Elastic modulus: 210000 (Unit: Mpa)	Poisson ratio: 0.295 (Range: 0-0.5)	Grid density: 3 (Range: 1-10 The smaller the value, the denser the grid)	
	Density: 7810E-9 (Unit: kg/mm³)	Leading force: 68400 (Unit: N)		

Buttons: [Start analysis] [Refresh]

(a)Parameter input

(b)Analysis results

Fig.4 Parametric CAE static analysis of dumbbell pin of scraper conveyor

4. Research on resources scheduling of intelligent cloud manufacturing for fully mechanized coal mining equipment

4.1 Manufacturing resources scheduling scheme

The cloud manufacturing resources of fully mechanized coal mining equipment are distributed in different geographical locations, with various types and specifications. The resources consumed by the design, simulation and manufacturing tasks of each coal machine are different. Therefore, the research of cloud manufacturing resource scheduling is particularly necessary [17]. In the process of manufacturing resources scheduling, firstly, through information technology, the available manufacturing resources are virtualized to form a set of rich and complete manufacturing services. When users put forward manufacturing tasks, they are divided into several sub tasks according to the product demand, manufacturing cost and time of the task, and manufacturing resources are integrated

and scheduled in the cloud manufacturing resources integration and scheduling system source matching and scheduling, and finally determine the implementation plan. The manufacturing resources scheduling scheme is presented in Fig.5.

Fig.5 Manufacturing resources scheduling scheme

With the complexity of solving the resource scheduling problem, the scale of the combinatorial optimization problem will dramatically increase. Besides, using the traditional enumeration method to find the optimal solution will only make the solution time longer and decrease its accuracy. At present, the research on scheduling in a cloud manufacturing environment mainly focuses on the ant colony algorithm, genetic algorithm, particle swarm optimization algorithm, game algorithm, and other intelligent optimization algorithms [18-22]. Among them, the particle swarm optimization algorithm is suitable for solving real number problems, which are simple, easy to calculate, and fast to solve. However, it has some problems such as falling into a local optimum. The ant colony algorithm is suitable for solving the problem of path searching on a graph. However, due to the lack of pheromone in the initial stage, the time of accumulating pheromone in the initial stage of search is longer. The lack of a pheromone in the initial stage leads to the longtime of the accumulating pheromone in the initial stage of searching.

In comparison, the genetic algorithm has the advantage of not relying on gradient information or other auxiliary knowledge in the calculation process. Also, only the objective and fitness functions affect the search direction, which has strong robustness and is more suitable for the complex and diverse scheduling tasks in the cloud manufacturing platform. However, the genetic algorithm converges to the local optimal solution prematurely, that is, the problem of “prematurity” and the problem of low local searchability. In this study, a genetic algorithm with an adaptive operation is proposed to solve the scheduling problem of cloud manufacturing resources.

4.2 A description of the manufacturing resources scheduling problem

The scheduling method in the cloud manufacturing

service system directly affects the final scheme of cloud manufacturing, which is an important part of the cloud manufacturing service system. Manufacturing resources scheduling is described as follows: a manufacturing task F submitted by the user, which contains l phase tasks $F_1, F_2, F_3, \dots, F_l$, where $F_k (1 \leq k \leq l)$ denotes the k phase task. Then, each phase task is divided into n subtasks $F_{k1}, F_{k2}, F_{k3}, \dots, F_{kn}$, where $F_{ki} (1 \leq i \leq n)$ denotes the i subtask in the k phase task. The subtask F_{ki} has m optional services $V_{ki1}, V_{ki2}, V_{ki3}, \dots, V_{kim}$ in the cloud manufacturing platform, where $V_{kij} (1 \leq j \leq m)$ denotes the j service of the subtask i in phase k . Then, the corresponding relation between F_k and V can be expressed by the relation matrix X :

$$X_k = \begin{bmatrix} x_{k11} & x_{k12} & \dots & x_{k1n} \\ x_{k21} & x_{k22} & \dots & x_{k2n} \\ \dots & \dots & \dots & \dots \\ x_{km1} & x_{km2} & \dots & x_{kmn} \end{bmatrix}. \text{ The decision-making}$$

of each subtask is defined as $x_{kij} (1 \leq i \leq n, 1 \leq j \leq m, 1 \leq k \leq l), x_{kij} \in \{0, 1\}$, where $x_{kij} = 1$ indicates that the subtask i of the phase k task selects the j service. $x_{kij} = 0$ indicates that the subtask i of the phase k task does not select the j service, and the expected time for the j service completion of the subtask i of the phase k task is defined as t_{kij} . The manufacturing cost is defined as e_{kij} , and the satisfaction is positioned as a_{kij} . In this manufacturing task, the time of a subtask is

$$T_{ki} = \sum_{j=1}^m (t_{kij} \times x_{kij}), \text{ the manufacturing cost is}$$

$$E_{ki} = \sum_{j=1}^m (e_{kij} \times x_{kij}), \text{ and the satisfaction is}$$

$$A_{ki} = \sum_{j=1}^m (a_{kij} \times x_{kij}).$$

In summary, the total duration of the manufacturing task is

$$T = \sum_{k=1}^l \left(\max \left\{ \sum_{j=1}^m (t_{kij} \times x_{kij}) \right\} \right), \text{ the total cost is}$$

$$E = \sum_{k=1}^l \sum_{i=1}^n \sum_{j=1}^m (e_{kij} \times x_{kij}), \text{ and the final satisfaction}$$

$$\text{is } A = \sum_{k=1}^l \sum_{i=1}^n \sum_{j=1}^m (a_{kij} \times x_{kij}).$$

4.3 Multi-objective resources scheduling based on the adaptive genetic algorithm

The genetic algorithm is a computational model that simulates the natural evolution and biological mechanism of Darwin's biological evolution theory, and it is a method for searching for the optimal solution by simulating the natural evolution process. The general process of the genetic algorithm is presented in Fig.6.

Fig.6 Manufacturing resources scheduling scheme

(1) Coding

According to the characteristics of the scheduling model, a binary coding method based on phase tasks and subtasks is selected, and the candidate services are randomly selected according to the sequence of the subtasks for coding. The coding length is determined by the number of phase tasks, the number of subtasks in each phase, and the number of optional services in the subtasks.

(2) Calculate fitness function

Taking the manufacturing time, manufacturing cost, and final satisfaction as objective functions, the fitness function of the task is defined as:

$$F = aT_0 + bE_0 + cA_0 \quad (1)$$

$$T_0 = \sum_{k=1}^l \sum_{i=1}^n \frac{T_{\max} - T_{ki}}{T_{\max} - T_{\min}} \quad (2)$$

$$E_0 = \sum_{k=1}^l \sum_{i=1}^n \frac{E_{\max} - E_{ki}}{E_{\max} - E_{\min}} \quad (3)$$

$$A_0 = \sum_{k=1}^l \sum_{i=1}^n \frac{A_{ki} - A_{\min}}{A_{\max} - A_{\min}} \quad (4)$$

where a, b, and c denote the weight of time, cost, and satisfaction, respectively, meeting the requirements of $a + b + c = 1$. T_0 , E_0 , and A_0 denote the total length of the manufacturing service, the total manufacturing cost, and the final manufacturing satisfaction after normalization, respectively. $T_{\max} = \max\{T_{ki}\}$, $T_{\min} = \min\{T_{ki}\}$, and so on.

In summary, the goal of scheduling an algorithm is to find an optimal relation matrix X_k in each stage task so that the fitness function F can get the maximum value.

(3) Selection operation

The probability of the individual i in entering the next generation is directly related to its fitness function value and the selection probability

$$P_s = 1 - F_i / \sum_{i=1}^k F_i \quad (5)$$

, where k is the number of individuals in the population, and F_i is the fitness value of the i th subtask.

(4) Crossover and mutation operation

The crossover and mutation operations are based on the services selected by the subtasks. One or more subtasks that need to be crossed and mutated are randomly selected for the crossover and mutation operations of the service selection. In the early stage of the algorithm iteration, due to the randomness of its generation, there are great differences among the individuals, and increasing the probability of mutation and crossover can make it converge quickly. In the later stage of the algorithm iteration, the difference among the individuals in the population is small, and reducing the probability of mutation and crossover can retain the excellent gene structure generated by the iteration and make the algorithm converge quickly. The generation g crossover probability is represented by

$$P_{c(g)} = (F_e^2 + F_c^2)^{\frac{1}{2}} \times \left(1 - \frac{g}{G}\right) \quad (6)$$

$$F_e = (F_{\max} - F_{\text{avg}}) / (F_{\max} - F_{\min}) \quad (7)$$

$$F_c = (F_{\max} - F_f) / (F_{\max} - F_{\min}) \quad (8)$$

where $P_{c(g)}$ denotes the crossover probability of the g th generation, and G denotes the total number of iterations. $F_{\max}$ and $F_{\min}$ denote the maximum and minimum fitness values, respectively, and F_{avg} and F_f denote the average fitness values and the fitness values of the larger individuals among the two crossover parents, respectively.

The mutation probability of an individual in the generation g th is represented by

$$P_{m(t)} = \frac{F_m}{1 + F_e} \times \frac{\arctan\left(g^{\frac{1}{2}}\right)}{\pi} \quad (9)$$

$$F_m = (F_{\max} - F_f) / (F_{\max} - F_{\min}) \quad (10)$$

4.4 Experimental verification

Taking the roadheader as an example, the resource scheduling problem in its cloud manufacturing process verifies the applicability of this algorithm model. The manufacturing project of the roadheader includes the design, manufacturing, assembly, and other production stages. Each stage task contains several subtasks, and each subtask has several optional services. Some service resources matched in the cloud manufacturing service system are presented in Table 1.

Table 1 Some resources in the Cloud Manufacturing platform

Phased mission	1				2				3				4			
Subtask	1				2				3				1			
Additional service	1	2	1	2	3	4	1	2	3	1	2	3	1	2	3	4
Required time(hours)	40	28	22	26	42	37	25	30	22	60	48	72	43	35	21	24
Required cost(thousands)	47	20	35	35	60	50	70	88	73	81	90	75	90	77	90	33
Satisfaction (quality etc.)	76	49	67	67	80	78	71	65	78	65	79	59	83	65	91	75

The algorithm is implemented as follows:

(1) Initialization parameters

Taking the population number 10 as an example to illustrate the implementation process of the algorithm, the maximum genetic algebra is set to 100, and the required time, required cost, and final satisfaction weight are 0.4, 0.4, and 0.2, respectively.

(2) Coding

Using a binary encoding method based on the phase task and subtask, this task has 4 phase tasks, 9 subtasks, and 23 optional services. The coding diagram is presented in Fig.7.

Fig.7 Coding diagram

(3) Selection operation

Randomly generating the initial population, calculating the fitness value of each individual, and making a generation selection. The selection operation is presented in Table 2.

Table 2 Selection operation

Indivi-dual	Chromo-some	Fit-ness	Selection probability	Number of selection	Selection result
1	01101011001010	2.306	0.123	3	1101011001010
2	00110010110101	1.174	0.063	0	1101011001010
3	00001111100110	2.145	0.115	1	1101011001010
4	11010011100100	1.725	0.092	0	0001111100110
5	10001010011010	1.281	0.069	1	0001010011010
6	00100001100010	1.863	0.010	0	0001110111011
7	00001110111011	2.889	0.155	2	0001110111011
8	11001101000010	1.377	0.074	0	0101100110100
9	00101100110100	1.785	0.096	2	0101100110100
10	11010100110011	2.132	0.114	1	1010100110011

(4) Crossover operation

First, the population was randomly paired. Then, the intersection location was set up with phase tasks and random blocks, and finally, the exchange was carried out according to the crossing probability P_c . The cross operation is presented in Table 3.

Table 3 Crossover operation

Indivi -dual	Chromosome	Match result	Crossover probability	Cross result
1	01101011001010	01101 011001010	0.681	01101011001010
2	01101011001010	00001 111100110		00001111100110
3	01101011001010	0110101100 1010		01101011001011
4	00001111100110	0000111011 1011	0.589	00001110111010
5	10001010011010	011 01011001010		01101100110100
6	00001110111011	001 01100110100		00101011001010
7	00001110111011	100010100 11010	0.732	00001110111011
8	00101100110100	110101001 10011		11010100111010
9	00101100110100	00001110 111011		00001110110100
10	11010100110011	00101100 110100	0.839	00101100111011

(5) Mutation operation

First, the positions of the mutation points of each individual were randomly generated, where the number of the mutation points indicates the sequence of the subtasks on the chromosome. Then, the genes were randomly mutated according to the mutation probability p_m . The mutation operation is presented in Table 4.

Table 4 Mutation operation

Indivi -dual	Chromosome	Mutation point	Mutation probability	Mutation results
1	01101011001010	4 01101 01 1001010	0.286	01101011001010
2	01101011001011	5 0110101 1 001011	0.843	01101010001011
3	01101011001011	2 0 11 01011001011	0.365	01101011001011
4	00001110111010	6 00001110 1 11010	0.572	00001110111010
5	01101100110100	2 0 11 01100110100	0.821	01001100110100
6	00101011001010	7 001010110 0 1010	0.504	00101011001010
7	10001010010011	1 1 0001010010011	0	10001010010011
8	11010100111010	3 110 10 100111010	0.743	11001100111010
9	00001110110100	7 000011101 1 0100	0.543	00001110100100
10	00101100111011	9 001011001110 11	0.372	00101100111011

(6) Recycling operation

Repeat the above steps 3, 4, and 5 and select the optimal individual according to the order of the fitness value. When the convergence condition is met or the maximum number of iterations is reached, the optimal individual is decoded, and the scheduling result is output.

By programming in MATLAB, after setting the initial parameters, the obtained curve of the number of iterations and the fitness value is presented in Fig.8. It can be seen from the figure that the maximum fitness value appears when iterating 32 times and when the corresponding code of the best service scheme is 10010111010110. The output scheduling scheme after transcoding is as follows: the selected service number of two subtasks in phase I is 2, 1; the selected service number of three subtasks in phase II is 3, 4, 2; the selected service number of three subtasks in phase III is 1, 2, 2; and the selected service number of one subtask in phase IV is 3. Under the condition that the subtasks of each phase can be carried out at the same time, the manufacturing task plan needs 149 h (the total cumulative time of each subtask is 250 h), the cost is 481 thousand RMB, and the expected final satisfaction is 670.

Fig.8 The curve of iteration degree and fitness value

The results reveal that the algorithm model has the potential to be used for global search and that the result is more accurate and has a fast convergence speed, which is ideal for manufacturing resources scheduling.

At present, the "Intelligent cloud manufacturing resources integration and scheduling system for coal mining equipment" has been successfully launched, and it is welcomed by many coal machinery equipment manufacturing enterprises and coal mine design institutes in Shanxi province and China, especially the functions of type selection design and CAE analysis of coal mine machinery and equipment, which makes more than 10 application enterprises. It improves the technological innovation ability and the reuse ability of knowledge assets of application enterprises, drives a batch of application and technology research and system development, and brings considerable economic benefits to the above application units.

5. Conclusions

(1) Nowadays, there is a strong demand for intelligent cloud manufacturing resources and services in the field of fully mechanized coal mining equipment. The intelligent cloud manufacturing service system for fully mechanized coal mining equipment can realize the integration and sharing of resources, such as the design, calculation, data, simulation, and services of coal mining and transportation equipment in the cloud manufacturing environment, and it has a broad development space.

(2) The resources integration system has realized the digital designs, manufacturing, and testing of the key parts and complete machines of fully mechanized coal mining equipment. The system can improve the structure, stability, and system dynamic performance of the whole machine and parts of the fully mechanized mining equipment, shorten the design cycle, reduce the R&D cost, improve the reliability of the equipment, and realize the digital collaborative design and manufacturing of the fully mechanized coal mining equipment in the industrial Internet environment.

(3) The cloud manufacturing resources scheduling method that is based on the adaptive genetic algorithm can obtain more accurate scheduling results with the potential to be used for global search. Moreover, it has a fast convergence speed and is an ideal method for solving manufacturing resources scheduling.

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Figures

Figure 1

The supporting frame of industrial internet

Figure 2

Overall framework of intelligent cloud manufacturing resources integration and scheduling system

Figure 3

Function of resources integration system

CAD 建模

Three-dimension graph

Two-dimension graph

Parameter bit

LA	362	HB	42	LB	225	HC	27
LC	90	HD	20	LD	27	HE	40
LE	16	D1	100	LF	40	D2	60
LG	67	D3	30	HA	78		

Determination

CAE analysis

Analysis types

Static Analysis	Non-prestressed modal analysis	Prestressed modal analysis	Harmonic response analysis	Transient analysis
Input parameters	Elastic modulus	210000	(Unit: Mpa)	
	Poisson ratio	0.295	(Range: 0-0.5)	
	Grid density	3	(Range: 1-10 The smaller the value, the denser the grid)	
	Density	7810E-9	(Unit: kg/mm³)	
	Loading force	68400	(Unit: N)	Loading force description
		Start analysis	Refresh	

(a)Parameter input

(b)Analysis results

Figure 4

Parametric CAE static analysis of dumbbell pin of scraper conveyor